REMARKS

In light of the above amendatory matter and remarks to file, reconsideration and allowance of this application are respectfully solicited.

Claims 35, 37, 47, 51, 52, 55, 68 and 70 are amended to delete therefrom the word "typical" or "typically," as the case may be. Claim 50 is amended to delete therefrom the expressions "an energy bandgap significantly more..." and "preferably at least twice...." Accordingly, the withdrawal of the rejection of claims 35, 37, 47, 49-52, 55-57, 59, 60, 64-66 and 68-70 under 35 USC 112 is respectfully requested.

The Examiner kindly found claims 45, 68 and 70 as defining patentable subject matter. Claims 33-37, 39-44, 46-52, 55-67 and 69 stand rejected in view of U.S. Patent 6,803,557 (Taylor). Taylor was applied as an anticipatory reference against claims 33-35, 37, 39-42, 44, 46, 48, 50-52, 56-58, 60-67 and 69; and was relied upon as evidence of the alleged obviousness of claim 36. Taylor was combined with Johnson (Journal of Applied Physics, volume 80, pages 1116-1127) to reject claims 43, 47, 49, 55 and 59 as being obvious.

By this amendment, claims 33 and 50 are amended to clarify that which was implicit heretofore. New claims 71-73 are added to round out the scope of protection to which applicant is entitled. The amendments made to the claims are presented simply for clarification or to improve the language thereof. Such amendments are not made for the purpose of patentability pursuant to 35 USC 101, 102, 103 or 112.

At the outset, it should be appreciated that the examples referred to in these Remarks are illustrative only. Applicant's invention is defined by the claims and should not be limited solely to the examples discussed here or provided in the specification.

The present invention provides a novel photo-detector comprising **at least two heterojunctions** defined by at least three layers of different materials, one of them being a

photon absorbing layer. The invention is aimed at reducing generation recombination (GR) dark current (as compared with a p-n homo-junction photo-detector made from the same photon absorbing material), by preventing the creation of a depletion region in the photon absorbing layer, i.e. eliminating or at least significantly reducing any internal or built-in electric field in the photon absorbing layer. This is achieved by providing the photon absorbing layer and interfacing therewith a middle barrier layer of the same conductivity type selected such that the photon-absorbing layer has a relatively narrow energy bandgap as compared to that of the middle barrier layer.

In other words, the photo-detector of the invention is a multi-layer structure defining **at least two hetero-junctions formed by, respectively, the photon absorbing and middle barrier layer and the middle barrier and contact layers where the photon absorbing layer has a narrower energy bandgap than the middle barrier layer**. The heterostructure has an n-type middle barrier layer and the photon-absorbing layer is then also n-type (Claim 33) – see for example paragraph [0085] of Applicant's corresponding published application; or the heterostructure has a p-type middle barrier layer and the photon-absorbing layer is then also p-type (Claim 50) – see for example paragraph [0098]. As a result of the claimed construction, minority carriers generated in the photon absorbing layer in response to its interaction with incident photons can only pass into the middle barrier layer by diffusion, and other currents due to majority carriers such as interband tunneling through, or thermal excitation over the barrier are suppressed.

It should be understood that in the configuration of the photo-detector of the present invention, the region of the photo-detector that contributes to the photocurrent signal *does not* contribute to any G-R noise, i.e. has no G-R noise component. In this connection, it should be understood that a source of such G-R noise component is associated with a depletion region. In

conventional devices, such as described in the references relied upon by the Examiner, the depletion region is in the photon absorbing layer and therefore G-R noise contributes to the photo current signal. In contradistinction therewith, in the invention the depletion region of the device is in the barrier layer (and not in the photon absorbing layer) which has a much larger bandgap than that of the photon absorbing layer. Therefore, the G-R noise is strongly suppressed, because the G-R noise is reduced exponentially with the bandgap.

Claims 33 and 50 have been amended and claims 71 and 73 have been added to clarify the above-mentioned feature. The amendments find full support in the specification. Examples of such support are found at the following paragraphs in applicant's corresponding published application:

paragraph [0091]: "During operation ... an electric field and associated **depletion region is allowed only in the contact layer** 11, 21, 35 or 39 **and in the barrier layer** 12,12A, 16,16A, 26 or 34 **but not in the active photon-absorbing layer** 13, 13A, 23 or 33" *** "The G-R contribution to the dark current from the active photon-absorbing layer 13, 13A, 23 or 33 is in fact comparable to the diffusion dark current from this layer. **The current flowing from this layer 13, 13A, 23 or 33 into the barrier layer 12, 12A, 16, 16A, 26 or 34 is therefore essentially diffusion limited.**"

paragraph [0085]: " A 3-layer, or **two hetero-junction**, light detector (a hetero-junction is a junction between different materials), of the form of **p-p-n or p-n-n is used**, wherein the last n-layer 13, 13A, 23 or 33 has a narrow gap chosen for its cut-off wavelength and the middle-layer 12, 12A, 16, 16A, 26 or 34 has a wider band-gap."

paragraph [0098]: "The principles of the present invention described above also apply to inverted polarity structures of the form n-n-p or n-p-p in which all the doping polarities and band alignments described above are reversed. An example is shown in FIG. 3 of an n-p-p structure

that is the reversed form of the p-n-n structure depicted in FIGS. 2a-2d. The photon absorbing layer 43 is p-type 47 while the contact layer 45 is n-type and barrier layer 44 is p-type."

paragraph [0089]: "The materials forming the photo-detector of the invention are chosen such that in a flat band condition either **the photon-absorbing layer** 13, 13A, 23 or 33 **or the barrier layer** 12, 12A, 16, 16A, 26 or 34 **has the lowest valence band energy**, and **the valence band of the photon absorbing layer is never more than about $10kT_{op}$ above the valence band of the barrier layer**, where T_{op} is the absolute operating temperature."

paragraph [0027]: "...there being no layer with **a narrower energy bandgap than that in the photon-absorbing layer**".

paragraph [0087]: " The middle layer 12, 12A, 16, 16A, 26 or 34 (again, depending on the specific embodiment used) **prevents inter-band tunneling of electrons from the valence band of the p-type layer 11, 21, 35 or 39 to the conduction band of the photon-absorbing layer.**"

paragraph [0095]: " *** In general, the activation energy for **electrons passing from the contact layer** 11,21,35 or 39 **into the barrier layer** 12, 12A, 16, 16A, 26 or 34 will then be greater than E_G^{α}, even when G-R centers are present in the contact layer 11, 21,35 or 39. Under these circumstances, **the current due to this process will be less than the diffusion current from the photon absorbing layer** 13, 13A 23 or 33 **which also has an activation energy** E_G^{α}.

paragraph [0096]:" Furthermore, the thickness of the barrier layer 12, 12A, 16, 16A, 26 or 34 is made to be sufficiently thick **to suppress any tunnel current of electrons from the valence band of the p-type contact layer 11, 21, 35 or 39 to the conduction band of the active photon absorbing layer 13, 13A, 23 or 33. Any such tunnel current must be less than the dark current in the diode due to other processes**"

paragraph [0093]: "*** the G-R dark current contribution from the barrier-layer 12, 12A, 16, 16A, 26 or 34 should be comparable with, or less than the total contribution to **the dark current due to the active photon absorbing layer** 13, 13A, 23 or 33 **which is diffusion limited...**"

Taylor describes a photodiode being a multi-layer structure which, contrary to the invention of, for example, claim 33, is configured to define one or more p-n junctions such that a photon absorbing layer interfaces a different-type conductivity layer and where, at the interface, the photon absorbing layer has the *same* energy band gap as the different-type conductivity layer. The multi-layer structure of Taylor is not a heterostructure -- Taylor uses the same material layers but with different, gradually changing composition.

Referring to **Fig. 2** of Taylor, the broken line shows the band profile when the device is biased. The left hand vertical line with a wavy arrow next to it, indicates the *minimum* characteristic energy of light which is absorbed and then contributes to the current signal when the device is biased. This line is at the boundary of the depletion region. Light with a larger photon energy is absorbed in the depletion region which lies to the right of this vertical line and "photo-generated holes can be captured by the electric field in the depletion region 17 instead of recombining outside of the depletion region 17" [Taylor, Column 6, lines 56-59]. The photo-generated holes hence contribute to the signal. Light with a smaller energy is absorbed outside the depletion region and does not contribute to the signal because the holes are driven away from the depletion region by the electric field caused by the compositional gradient, where they end up "recombining outside the depletion region" [Taylor, Column 6, lines 58-59]". Therefore, the G-R noise comes only from the depletion region. Thus, the *same* region of the device, namely the depletion region, contributes both to the photocurrent signal and to the G-R noise<u>, so the G-R noise is not suppressed</u>.

It is respectfully submitted, Applicant's heterostructure formed by two hetero-junctions of n-n-p (Claim 33) or p-p-n (Claim 50) layers, with photon absorbing layer having the narrower energy bandgap than the interfacing p- or n-type layer, respectively, is different from the multi-layer structure of Taylor which has layers of the same material but with different, gradually changing composition. Also, the multi-layer structure of Taylor operates differently than that of Applicant's claim 33 or 50.

Claim 36 depends from Claim 33 and includes all of the features recited by claim 33. Since claim 33 is patentably distinct from Taylor, it follows that dependent claim 36 likewise is unobvious over Taylor for the same reasoning discussed above in connection with Claim 33.

Claims 43, 47, 49, 55 and 59 are rejected under 35 USC 103 in view of the combination of Taylor and Johnson. These claims are dependent on Claims 33 and 50 and, therefore, these dependent claims include all of the features recited by a respective one of the independent claims. Johnson was cited for a description of SLS materials; but fails to cure the aforenoted deficiencies of Taylor. Therefore, the above arguments set out in connection with Claim 33 are equally applicable to claims 43, 47, 49, 55 and 59; and the rejection of claims 43, 47, 49, 55 and 59 should be withdrawn for the foregoing reasons.

Statements appearing above in respect to the disclosures in the cited references represent the present opinions of the undersigned attorney and, in the event the Examiner disagrees with any of such opinions, it is respectfully requested that the Examiner specifically indicate those portions of the references providing the basis for a contrary view.

Please charge any additional fees that may be needed, and credit any overpayment, to our Deposit Account No. 50-0320.

Respectfully submitted,

FROMMER LAWRENCE & HAUG LLP
Attorney for Applicants

By: William Frommer
William S. Frommer
Reg. No. 25,506
(212) 588-0800